Man Eats Forest

Impacts of Cattle Ranching on Amazon Deforestation

Nikolas Kuschnig & **Lukas Vashold***

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*Vienna University of Economics and Business
Department of Economics & Institute for Ecological Economics
lukas.vashold@wu.ac.at

Motivation

- **Amazon deforestation** continues to be an issue, threatening
  - local *biodiversity* and *livelihoods* (Gibson et al. 2011; Villén-Pérez et al. 2022)
  - regional and global *climates* (Leite-Filho et al. 2021; Araujo et al. 2023)
- In Brazil, **demand for land** primarily stems from **agriculture**,
  - with **cattle** and *soy* being the predominant factors (Rajão et al. 2020)
  - mining and other agricultural products play a limited role (Garrett et al. 2021)
- But no framework for **causal interpretation** of its deforestation impacts,
  - footprint analyses lack causal interpretability
  - naive regressions indicate *limited impacts*

This paper

Uses a shift-share design to **causally identify and quantify** the deforestation impacts of the **demand-driven cattle expansion** in the Legal Amazon

Legal Amazon in 2000

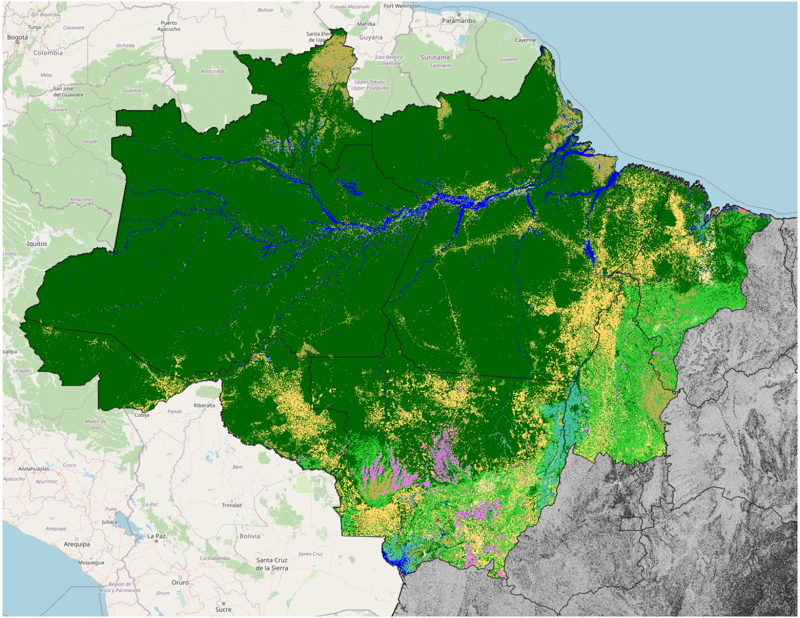


Chart: Land cover, including **forest**, **pasture**, and **croplands**, in the Legal Amazon in 2000.

Legal Amazon in 2022

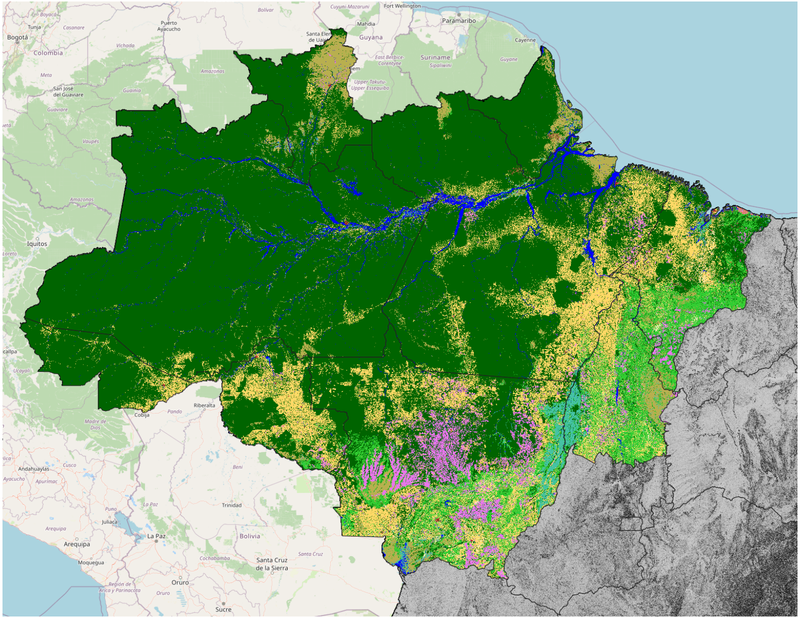


Chart: Land cover, including **forest**, **pasture**, and **croplands**, in the Legal Amazon in 2022.

Background, Deforestation in Brazil

Reasons for high levels and resurgence include:

- strong and rising **demand for agricultural products**, especially **beef products**[a]
  - can be met with *intensification*, or deforestation at the *extensive margin*.
- weak *land governance* enabling speculative **land appropriation**[b]
  - forest is cut, agricultural activities are feigned, and ownership is claimed.
- *policy interventions* being **not resilient** with respect to political influence[c]

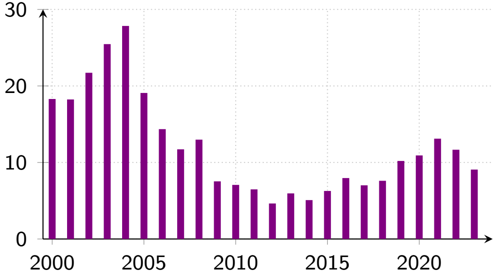


Chart: Deforestation in the Brazilian Amazon (in 1,000 km^2).

a. Cusack et al. 2021; Pendrill et al. 2022.

b. Reydon, Fernandes, and Telles 2020.

c. Garrett et al. 2021; Kuschnig et al. 2023; Burgess, Costa, and Olken 2024.

Background, Cattle & Beef in Brazil

The cattle and beef industry in Brazil...

- ...is important for the national economy at **8% of GDP** (CEPEA 2023), and the livelihoods of local farmers specifically (Ermgassen et al. 2020),
- ...is moving deeper into the Amazon (Vale et al. 2022) and is the **proximate cause of ~90-95% of deforestation** there (Haddad et al. 2024),
- ...is linked to deforestation that accounts for a **fifth of global land use emissions** from the tropics, ~500MT per year (Pendrill et al. 2019),
- ...and, due to the mobility of cattle, acts as the **main intermediary for land appropriations** in the Amazon (Fearnside 2017).

Empirical Specification

Empirical Specification

- We depart from a simple (first-difference) panel regression specification:

$$\Delta y_{i,t} = \beta \Delta c_{i,t} + \Delta \boldsymbol{X}'_{i,t-s}\gamma + \mu_t + u_{i,t}$$
$$\Delta c_{i,t} = \Delta \boldsymbol{X}_{i,t-s}\boldsymbol{\alpha} + \omega B_{i,t} + \mu_t^b + \varepsilon_{i,t}$$

  - $\Delta y_{i,t}$ denotes **forest change** in municipality i at time t,
  - $\Delta c_{i,t}$ is a measure of **cattle expansion** (e.g. change in cattle head),
  - $\boldsymbol{X}_{i,t-s}$ holds various control variables, and μ_t are time-fixed effects.

- And use the instrument $B_{i,t}$ to *causally identify* the effect of interest, β,
  - inter alia, as $c_{i,t}$ captures multiple drivers of the cattle expansion,
- to isolate the impacts of the *demand-driven cattle expansion* on deforestation.

Construction of the instrument ▸ Details

We construct the shift-share (or 'Bartik')[1] instrument $B_{i,t}$ as

$$B_{i,t} = \sum_m \frac{\text{exports}_{i,m,t=0}}{\text{exports}_{i,t=0}} z_{i,t=0}\, g_{m,t}$$

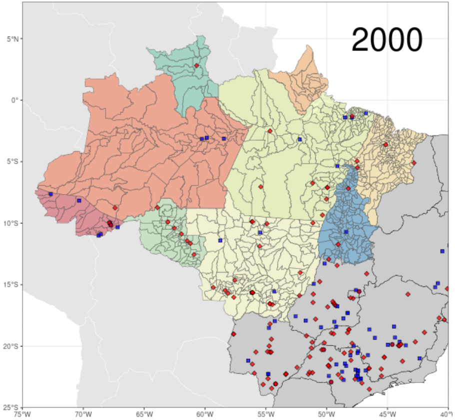
- Distance to slaughterhouse locations, interacted with municipality i's initial cattle stocks as **share** $z_{i,t=0}$ to measure exposure to beef industry
- Changes in international beef consumption as **shifts** $g_{m,t}$, where we consider
  (i) changes in **all export destinations** weighted by exports at the municipality level
  (ii) changes in **Chinese beef consumption** for periods lacking export information

Identification

We rely on *shift exogeneity for identification*, and exploit the *shares for relevance*

1. See Borusyak, Hull, and Jaravel 2022, for more details.

Shift-Share Instrument Components



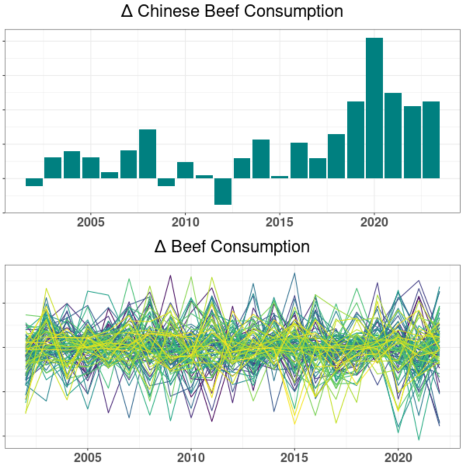


Chart: Slaughterhouse locations in 2000 and changes in aggregate beef consumption.
Sources: Vale et al. 2022; FAO 2023

Data & Sources

Main sample covers 808 municipalities in the Legal Amazon from 2003 until 2022:

- Land cover and land use change statistics (MapBiomas 2023)
- Socioeconomic and agricultural data (IBGE 2022)
- Environmental fines (IBAMA 2022)
- Protected areas (UNEP-WCMC and IUCN 2022)
- Meteorological indicators (Beguería, Vicente-Serrano, and Angulo-Martínez 2010)
- Slaughterhouse locations (Vale et al. 2022)
- Municipality-level beef exports (Ermgassen et al. 2020)
- International beef consumption (FAO 2023)

Results

Results, cattle expansion

	2003–2022		2011–2022		
ΔForest$\sim$	OLS	IV-CHN	OLS	IV-CHN	IV-EXP
ΔCattle	**-0.102**	**-0.402**	**-0.108**	**-0.425**	**-0.341**
	(0.02)	(0.13)	(0.03)	(0.13)	(0.10)
Covariates	Full	...			
Year FEs	Yes	...			
$N \times T$	16,160	16,160	9,696	...	
F stat (Cattle)		318.2		427.3	57.1

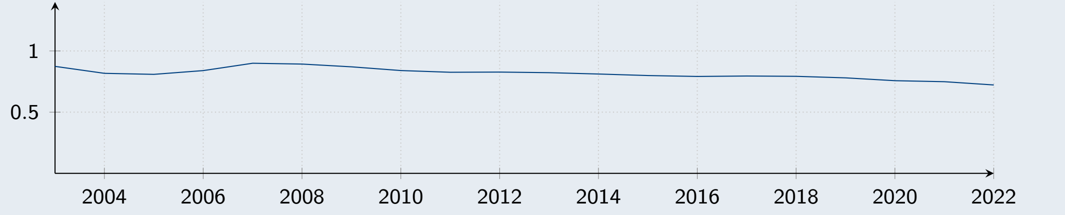
Standard errors clustered at the municipality-level. Significant ($p < 0.01$) estimates in **bold**.

Pasture expansion

Results, effect size

- *Stocking rates* suggest that **each cow** requires ∼**0.8 hectare** of grazing area[2]
- Reported **forest-to-pasture** transition rate of ∼**0.66 hectare** per cattle[3]
- Naive estimates suggest almost **decoupling** of cattle and land
- Our **instrumented estimates** are closer to those suggested by footprint analyses
  - but still amount to only **56–70%** of them
  - large share of observed deforestation **unexplained**

Pasture area per cattle head



2. Arantes et al. 2018.
3. MapBiomas 2023; IBGE 2022.

Results, biome heterogeneity

Biome	Amazon		Cerrado			
	ΔForest∼		ΔForest∼		*incl. Savanna*∼	
	OLS	IV	OLS	IV	OLS	IV
Cattle	**-0.107**	**-0.492**	-0.003	-0.014	**-0.027**	**-0.388**
	(0.03)	(0.15)	(.002)	(0.02)	(.005)	(0.18)
Covariates	Full	...				
Year FEs	Yes	...				
$N \times T$	10,060	...	21,240	...		
F stat		198.6		53.2		53.2

Standard errors clustered at the municipality-level. Significant ($p < 0.01$) estimates in **bold**.

Heterogeneity by governments

Results, intensification

	All biomes		Legal Amazon		Amazon biome	
ΔForest$\sim$	OLS	IV	OLS	IV	OLS	IV
ΔCattle per pasture	**0.054**	**0.239**	**0.104**	**0.470**	**0.158**	**0.746**
	(0.02)	(0.09)	(0.03)	(0.17)	(0.05)	(0.27)
Covariates	Full	...				
Year FEs	Yes	...				
$N \times T$	31,480	...	16,160	...	10,060	...
F stat		782.4		397.2		245.6

Standard errors clustered at the municipality-level. Significant ($p < 0.01$) estimates in **bold**.

Results, soy (preliminary)

	ΔForest$\sim$		ΔSavanna$\sim$		ΔPasture$\sim$	
	OLS	IV	OLS	IV	OLS	IV
ΔSoy (ha)	**-0.293**	**-0.312**	**-0.069**	**-0.295**	**-0.202**	**-0.483**
	(0.06)	(0.07)	(0.02)	(0.08)	(0.04)	(0.10)
ΔSoy (ton)	**-0.033**	**-0.066**	**-0.005**	**-0.060**	**-0.021**	**-0.097**
	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.03)
Covariates	Full	...				
Year FEs	Yes	...				
$N \times T$	16,160	...				
F stat (Soy, ha)		333.2		333.2		333.2
F stat (Soy, ton)		215.9		215.9		215.9

Standard errors clustered at the municipality-level. Significant ($p < 0.01$) estimates in **bold**.

Results, robustness

We assess the **sensitivity of results** along several dimensions:

- Varying **share** definitions
  - Different computations of distance to slaughterhouses
  - Omitting slaughterhouse location information
  - Updating shares over time
- **Sample** variations
  - All municipalities in Amazon, Cerrado, and Pantanal
  - Only municipalities with deforestation and 10% initial tree cover
- **Specification** variations
  - Including municipality FEs (time trends)
  - Excluding year FEs
  - Lag structure of treatment/instrument/controls

Conclusion

Implications

- The beef industry is considered a **driver of economic growth**
  - Monitoring *supply chains* complicated (Alix-Garcia and Gibbs 2017),
  - but recent initiatives (EUDR) could be role model for other markets
- **Land use externalities** lie at the heart of climate change
  - Beef has a *caloric efficiency* of 1.9%[4] and much higher land use for production[5]
- Few interventions **disincentivize** the demand for **LU-intensive food products**
  - **Domestic** tax restructuring more targeted[6]; **Global** GHG tax affects meat products[7]
  - Marketing restrictions and **information provision**, e.g. "do pasto ao prato"
- **Supply-side measures** to decrease land pressures from given demand
  - Targeted **credit provision** for intensification of existing pasture
  - Other measures to incentivize **restoration of pasture/forest** (similar to REDD+?)

4. Alexander et al. 2016.
5. Poore and Nemecek 2018.
6. Haddad et al. 2024.
7. Godfray et al. 2018.

Summary & Conclusion

- We **causally identify and quantify** the deforestation impacts of the **demand-driven cattle expansion** in the Legal Amazon
- Our results suggest that ...
  - ... the demand-driven expansion is a considerable causal driver of deforestation
  - ... effects are **underestimated** without proper identification
  - ... but explains only **56-70%** of observed cattle-related deforestation
  - ... intensification may alleviate land pressures, soy acts as indirect driver

For **more information**, download the slides or contact me at

- lukas.vashold@wu.ac.at
- www.vashold.eu

References I

Alexander, P., C. Brown, A. Arneth, J. Finnigan, and M. D. A. Rounsevell. 2016. "Human appropriation of land for food: The role of diet." *Global Environ. Change* 41:88–98. ISSN: 0959-3780. https://doi.org/10.1016/j.gloenvcha.2016.09.005.

Alix-Garcia, Jennifer, and Holly K. Gibbs. 2017. "Forest conservation effects of Brazill's zero deforestation cattle agreements undermined by leakage." *Global Environmental Change* 47:201–217. ISSN: 0959-3780. https://doi.org/10.1016/j.gloenvcha.2017.08.009.

Arantes, Arielle Elias, Victor Rezende de Moreira Couto, Edson Eyji Sano, and Laerte Guimares Ferreira. 2018. "Livestock intensification potential in Brazil based on agricultural census and satellite data analysis." *Pesquisa Agropecuria Brasileira* 53 (September): 1053–1060. ISSN: 0100-204X. https://doi.org/10.1590/S0100-204X2018000900009.

Araujo, Rafael, Juliano Assuno, Marina Hirota, and Jos A. Scheinkman. 2023. "Estimating the spatial amplification of damage caused by degradation in the Amazon." *Proceedings of the National Academy of Sciences* 120, no. 46 (November): e2312451120. https://doi.org/10.1073/pnas.2312451120.

Beguería, Santiago, Sergio M. Vicente-Serrano, and Marta Angulo-Martínez. 2010. "A multiscalar global drought dataset: the SPEIbase: a new gridded product for the analysis of drought variability and impacts." *Bulletin of the American Meteorological Society* 91 (10): 1351–1356. https://doi.org/10.1175/2010bams2988.1.

References II

Borusyak, Kirill, Peter Hull, and Xavier Jaravel. 2022. "Quasi-experimental shift-share research designs." *Review of Economic Studies* 89 (1): 181–213. ISSN: 0034-6527. https://doi.org/10.1093/restud/rdab030.

Burgess, Robin, Francisco Costa, and Ben Olken. 2024. *National Borders and the Conservation of Nature,* August. https://doi.org/10.31235/osf.io/67xg5.

CEPEA. 2023. *Brazilian Agribusiness GDP.* Retrieved at December $28^t h$ 2023 from: https://www.cepea.esalq.usp.br/en/brazilian-agribusiness-gdp.aspx. São Paulo, Brazil.

Cusack, Daniela F., Clare E. Kazanski, Alexandra Hedgpeth, Kenyon Chow, Amanda L. Cordeiro, Jason Karpman, and Rebecca Ryals. 2021. "Reducing climate impacts of beef production: A synthesis of life cycle assessments across management systems and global regions." *Global Change Biology* 27, no. 9 (May): 1721–1736. ISSN: 1354-1013. https://doi.org/10.1111/gcb.15509.

Ermgassen, Erasmus K. H. J. zu, Javier Godar, Michael J. Lathuillière, Pernilla Löfgren, Toby Gardner, André Vasconcelos, and Patrick Meyfroidt. 2020. "The origin, supply chain, and deforestation risk of Brazil's beef exports." *Proceedings of the National Academy of Sciences* 117, no. 50 (December): 31770–31779. ISSN: 0027-8424. https://doi.org/10.1073/pnas.2003270117.

FAO. 2023. *Food and Agriculture Statistics.* Retrieved on May 5^{th} 2023 from: https://www.fao.org/faostat/en/. Rome, Italy.

References III

Fearnside, Phillip. 2017. "Deforestation of the Brazilian Amazon." In *Oxford Research Encyclopedia of Environmental Science.* September. https://doi.org/10.1093/acrefore/9780199389414.013.102.

Garrett, Rachael D., Federico Cammelli, Joice Ferreira, Samuel A. Levy, Judson Valentim, and Ima Vieira. 2021. "Forests and sustainable development in the Brazilian Amazon: history, trends, and future prospects." *Annual Review of Environment and Resources* 46, no. 1 (October): 625–652. ISSN: 1543-5938. https://doi.org/10.1146/annurev-environ-012220-010228.

Gibson, Luke, Tien Ming Lee, Lian Pin Koh, Barry W. Brook, Toby A. Gardner, Jos Barlow, Carlos A. Peres, et al. 2011. "Primary forests are irreplaceable for sustaining tropical biodiversity." *Nature* 478 (October): 378–381. ISSN: 1476-4687. https://doi.org/10.1038/nature10425.

Godfray, H. Charles J., Paul Aveyard, Tara Garnett, Jim W. Hall, Timothy J. Key, Jamie Lorimer, Ray T. Pierrehumbert, Peter Scarborough, Marco Springmann, and Susan A. Jebb. 2018. "Meat consumption, health, and the environment." *Science* 361, no. 6399 (July). ISSN: 0036-8075. https://doi.org/10.1126/science.aam5324.

Haddad, Eduardo A., Incio F. Arajo, Rafael Feltran-Barbieri, Fernando S. Perobelli, Ademir Rocha, Karina S. Sass, and Carlos A. Nobre. 2024. "Economic drivers of deforestation in the Brazilian Legal Amazon." *Nature Sustainability* 7 (September): 1141–1148. ISSN: 2398-9629. https://doi.org/10.1038/s41893-024-01387-7.

References IV

IBAMA. 2022. *Dados Abertos.* Retrieved at September $16^t h$ 2022 from: https://dadosabertos.ibama.gov.br/. São Paulo, Brazil.

IBGE. 2022. *Sistema IBGE de recuperação automática.* Retrieved at September $16^t h$ 2022 from: https://sidra.ibge.gov.br/. São Paulo, Brazil.

Kuschnig, Nikolas, Lukas Vashold, Aline C. Soterroni, and Michael Obersteiner. 2023. “Eroding resilience of deforestation interventions—evidence from Brazil's lost decade.” *Environmental Research Letters* 18, no. 7 (July): 074039. ISSN: 1748-9326. https://doi.org/10.1088/1748-9326/acdfe7.

Leite-Filho, Argemiro Teixeira, Britaldo Silveira Soares-Filho, Juliana Leroy Davis, Gabriel Medeiros Abrahão, and Jan Börner. 2021. “Deforestation reduces rainfall and agricultural revenues in the Brazilian Amazon.” *Nature Communications* 12, no. 2591 (May): 1–7. ISSN: 2041-1723. https://doi.org/10.1038/s41467-021-22840-7.

MapBiomas. 2023. *Annual Land Use Land Cover Maps of Brazil.* Available at: https://mapbiomas.org/en. São Paulo, Brazil.

Pendrill, Florence, Toby A. Gardner, Patrick Meyfroidt, U. Martin Persson, Justin Adams, Tasso Azevedo, Mairon G. Bastos Lima, et al. 2022. “Disentangling the numbers behind agriculture-driven tropical deforestation.” *Science* 377, no. 6611 (September). ISSN: 0036-8075. https://doi.org/10.1126/science.abm9267.

References V

Pendrill, Florence, U. Martin Persson, Javier Godar, Thomas Kastner, Daniel Moran, Sarah Schmidt, and Richard Wood. 2019. "Agricultural and forestry trade drives large share of tropical deforestation emissions." *Global Environmental Change* 56:1–10. ISSN: 0959-3780. https://doi.org/10.1016/j.gloenvcha.2019.03.002.

Poore, J., and T. Nemecek. 2018. "Reducing food's environmental impacts through producers and consumers." *Science* 360 (6392): 987–992. ISSN: 0036-8075. https://doi.org/10.1126/science.aaq0216.

Rajão, Raoni, Britaldo Soares-Filho, Felipe Nunes, Jan Börner, Lilian Machado, Débora Assis, Amanda Oliveira, Luis Pinto, Vivian Ribeiro, and Lisa Rausch. 2020. "The rotten apples of Brazil's agribusiness." *Science* 369 (6501): 246–248. https://doi.org/10.1126/science.aba6646.

Reydon, Bastiaan Philip, Vitor Bukvar Fernandes, and Tiago Santos Telles. 2020. "Land governance as a precondition for decreasing deforestation in the Brazilian Amazon." *Land Use Policy* 94 (May): 104313. ISSN: 0264-8377. https://doi.org/10.1016/j.landusepol.2019.104313.

Souza-Rodrigues, Eduardo A. 2019. "Deforestation in the Amazon: a unified framework for estimation and policy analysis." *Review of Economic Studies,* https://doi.org/10.1093/restud/rdy070.

UN Comtrade. 2022. *United Nations Comtrade Database.* Retrieved on May 5th 2022 from: https://comtradeplus.un.org/. New York, US.

References VI

UNEP-WCMC and IUCN. 2022. *Protected Planet: The World Database on Protected Areas (WDPA).* Available at: www.protectedplanet.net. Cambridge, UK.

Vale, Ricardo, Petterson Vale, Holly Gibbs, Daniel Pedrn, Jens Engelmann, Ritaumaria Pereira, and Paulo Barreto. 2022. "Regional expansion of the beef industry in Brazil: from the coast to the Amazon, 1966–2017." *Regional Studies, Regional Science* 9, no. 1 (December): 641–664. https://doi.org/10.1080/21681376.2022.2130088.

Villén-Pérez, Sara, Luisa Anaya-Valenzuela, Denis Conrado da Cruz, and Philip M. Fearnside. 2022. "Mining threatens isolated indigenous peoples in the Brazilian Amazon." *Global Environmental Change* 72:102398. ISSN: 0959-3780. https://doi.org/10.1016/j.gloenvcha.2021.102398.

Appendix

Construction of the instrument ◂ Return

We construct our Bartik (or *shift-share*) instrument $B_{i,t}$ using:

- Distance to slaughterhouse locations, interacted with municipality i's proportion on overall pasture area/cattle head as **share** variable $z_{i,t=0}$.
  - Pasture *expansion is clustered* around relevant infrastructure
  - Transport costs are crucial factor for the profitability of agriculture (Souza-Rodrigues 2019), and slaughterhouses are an intermediate destination (Vale et al. 2022)

$$z_{i,t=0} = \exp\{-d_{i,t=0}\} \times \frac{1}{C_{t=0}} \sum_k c_{k,t=0} \, ,$$

- Changes in foreign (Chinese) beef consumption as **exogenous shift** variable g_t.
  - The demand is *relevant to* and partly satisfied with Brazilian beef,[8]
  - but is unlikely to affect Amazon deforestation in other ways.

$$g_t = \Delta \text{steak}_t^{CHN} .$$

8. UN Comtrade 2022; FAO 2023.

Construction of export-weighted instrument ◂ Return

We construct also an instrument based on export-weighted shocks:

- Beef consumption changes in m export destinations:

$$B_{i,t} = \sum_m z_{i,m,t=0} \, g_{m,t-1}$$

$$z_{i,m,t=0} = z_{i,t=0} \times \frac{\text{exports}_{i,m,t=0}}{\text{exports}_{i,t=0}},$$

  - where the share $z_{i,t=0}$ from before is interacted with export shares of destinations m.
  - Export shares at the municipality level are taken from Ermgassen et al. 2020, only available for period 2010–2020.

- Growth in beef consumption of market m as **shift** variable $g_{m,t}$.

Results, pasture expansion ◂ Return

ΔForest$\sim$	2003–2022 OLS	2003–2022 IV-CHN	2011–2022 OLS	2011–2022 IV-CHN	2011–2022 IV-EXP
ΔPasture	**-0.894**	**-0.973**	**-0.832**	**-0.976**	**-0.926**
	(0.03)	(0.03)	(0.04)	(0.03)	(0.04)
Covariates	Full	...			
Year FEs	Yes	...			
$N \times T$	16,160	16,160	9,696	...	
F stat (Pasture)		732.9		711.7	86.2

Standard errors clustered at the municipality-level. Significant ($p < 0.01$) estimates in **bold**.

Results, government heterogeneity

Return

	Lula		Rousseff		Temer		Bolsonaro	
ΔForest$\sim$	OLS	IV	OLS	IV	OLS	IV	OLS	IV
ΔCattle	**-0.097**	**-0.482**	**-0.046**	-0.137	**-0.085**	**-0.584**	**-0.158**	**-0.473**
	(0.03)	(0.08)	(0.01)	(0.07)	(0.03)	(0.16)	(0.04)	(0.13)
Covariates	Full	...						
Year FEs	Yes	...						
$N \times T$	6,464	6,464	4,040	4,040	2,424	2,424	3,232	3,232
F stat		147.4		36.8		62.4		269.7

Standard errors clustered at the municipality-level. Significant ($p < 0.01$) estimates in **bold**.